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PRINCIPLES AND PROPERTIES OF COLD MIRRORS

Introduction

The cold mirror, a vacuum deposited optical coating providing high visible reflectance coupled with high infrared transmittance, has been used for special applications in industry and the laboratory for a number of years. The ability of this coating to provide extremely high illumination with virtually no increase in temperature has made the cold mirror an excellent choice for medical and dental mirrors and for high intensity photographic projectors.

Since the cold mirror, besides having excellent temperature control properties, provides higher visible reflectance than first surface aluminum, it is useful in almost any optical system requiring a mirror. However, its major advantage occurs when focusing or collimating light from "hot" sources without appreciably heating the objects under illumination. This makes the cold mirror uniquely desirable in many experiments in biophysics, electro optics, photoconductivity, etc.

Perhaps the largest factor which has limited the use of cold mirrors in general laboratory work thus far has been the relatively high cost of such devices. Recent improvements in production techniques at Isomet have now made an assortment of spherical and flat cold mirrors available, as stock items, at unusually low cost. Even customer supplied substrates can now be coated for cold mirror properties at about the same cost as the multilayer mirrors common to the laser field.

Since these new developments have made cold mirrors economical for the first time, the remainder of this memorandum will briefly review the properties of these coatings.

All Dielectric Reflectors

Let us begin with a discussion of the properties of a simple, multilayer dielectric reflector. The most convenient starting place is the expression for the amplitude reflectance of a thin, homogeneous, nonabsorbing thin film on a homogeneous, nonabsorbing substrate. The derivation of this expression (from a consideration of multiple reflections within the film) is given in most texts on optics, and will not be repeated here. This expression is

$$r = \frac{r_1 + r_2\, e^{-2i\phi}}{1 + r_1 r_2\, e^{-2i\phi}}$$

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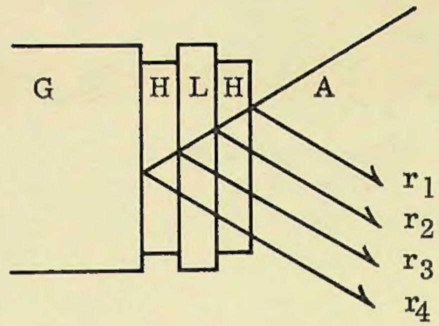
FIGURE 1.

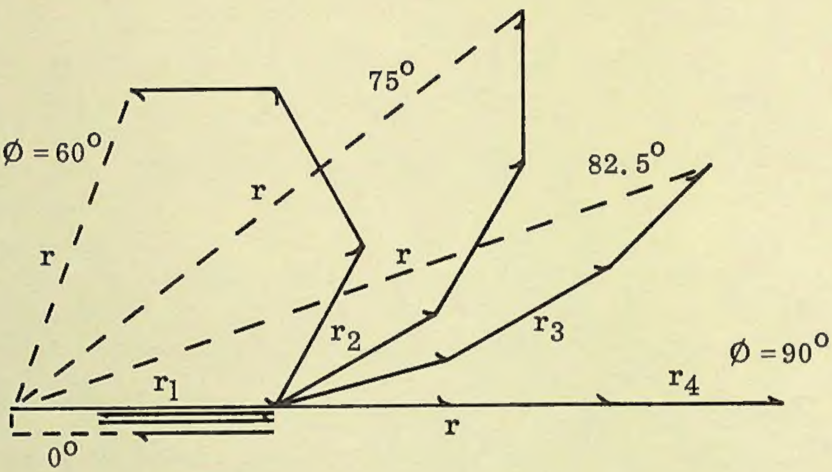
G(HLH)A

(A)

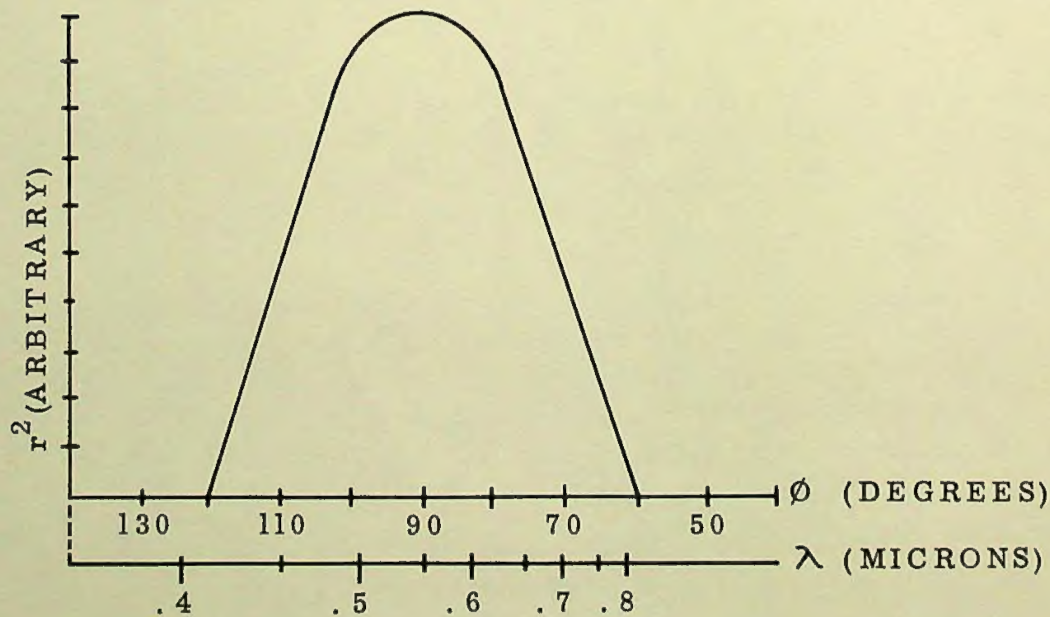


$N_G = 1.5$
$N_H = 2.3$
$N_L = 1.38$
$N_A = 1.0$

(B)



(C)



where r_1 and r_2 are the (Fresnel) reflectance coefficients at the first and second interfaces and ϕ is the optical (phase) thickness of the film. From this expression it can be seen that interference will be maximized when the film thickness is an integral number of quarter wavelengths. If the film is an odd number of quarterwaves thick, r will be a maximum or minimum, depending upon whether the film's index of refraction is higher or lower than that of the substrate. If the film thickness is an even number of quarter-waves, r will be identical to the amplitude reflectance of the uncoated substrate surface.

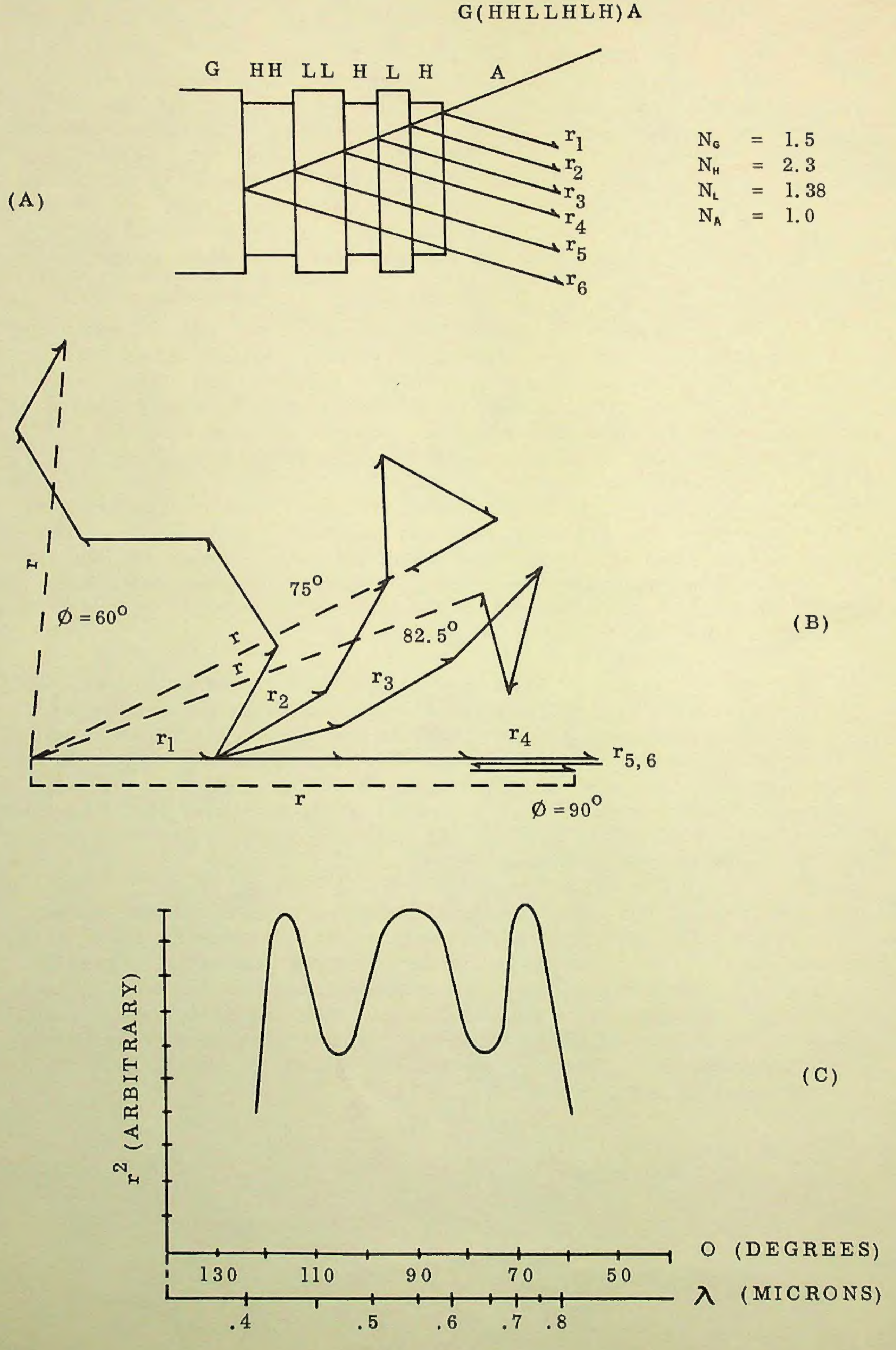
Because of the special properties of quarterwave films it is convenient to express coating designs in terms of quarterwave thickness units. The letter, H, represents a quarterwave film of high index and, L, a similar film of low index. Hence, the film combination HLH represents a three layer coating of alternate high and low index films, all of which are a quarterwave thick at the same reference wavelength.

An inexact, but very informative aid in visualizing the properties of multi-layer combinations utilizes a vector representation. In this method, vectors are drawn with lengths proportional to the Fresnel reflectance coefficient at each interface and rotated by angles (2ϕ) representing phase differences. The resultant vectors describe, qualitatively, the properties of the combination of films.

For example, Figure (1a) describes a three layer coating between glass and air. In Figure (1b) vectors are first drawn antiparallel to represent the reflectance coefficients for zero phase difference. The vectors are then allowed to rotate to the various phase difference angles which will occur in the combination as wavelength is varied. In Figure (1c) the square of the resultant vector (a measure of reflected intensity) is plotted against the phase thickness of the individual layers. In this example, the layers were chosen to be quarterwaves at 550 millimicrons.

As anticipated, the combination has a reflectance peak at the quarterwave position. Although Figure (1c) is not quantitative, the general shape of the reflectance curve indicates that the reflectance band is too narrow for use as a cold mirror. In addition, calculation indicates that the peak reflection of the G(HLH)A combination (for the materials used) is much too low. The reflectance can be increased by adding more quarterwave layers to the combination. However, other considerations are required in order to broaden the reflectance band.

FIGURE 2



G(HHLLHLH)A
G HH LL H L H A
r_1
r_2
r_3
r_4
r_5
r_6
N_G = 1.5
N_H = 2.3
N_L = 1.38
N_A = 1.0
(A)
r
Ø = 60°
75°
r
r
82.5°
r_2
r_3
r_1
r_4
$r_{5,6}$
r
Ø = 90°
(B)
r^2 (ARBITRARY)
(C)
130 110 90 70 50
O (DEGREES)
.4 .5 .6 .7 .8
λ (MICRONS)

Wide Band Reflectors

We have noticed that layers having a thickness equal to an even number of quarterwaves (e.g. one halfwave) do not alter the optical properties of a system. However, a layer may have half wave thickness at only one wavelength. Let us now examine the effects of such a layer as we depart from its halfwave value.

Consider the coating depicted in Figure (2a). This is essentially the same design discussed in Figure 1, with the addition of two halfwave layers. As expected, at the reference wavelength the vectors due to these additional layers fold back on themselves, giving rise to a resultant vector which is identical to the three layer case. However, as we leave the reference thickness, these two vectors begin to "curl" out, delaying the sharp fall in reflectance found in the original design. Figure (2c) indicates that the reflectance band has been broadened considerably. Note that there are severe minima on each side of the central reflectance peak. These could be lessened by changing the structure of the non-quarterwave layers or by increasing the number of quarterwave layers.

Since layers such as LL, HH, LLHHHH, etc., tend to broaden the spectral properties of a combination, they are often referred to as achromatizing layers.

Cold Mirrors

A practical cold mirror can be designed on the basis of the considerations outlined above. First, one must increase the number of layers in the reflecting stack. Next, one seeks out those achromatizing units which will extend the reflectance band over the entire visible region without introducing severe minima. A design which has been successfully applied to commercial use is G(HLHLHLHLHHLHHLHHLHH)A. The seven layer reflecting stack has a peak reflectance of about 97 percent. Since the HH layers do not alter the properties of the combination at the peak, the remaining four L layers may be regarded as a single LLLL achromatizing unit.

Figure 3 describes the optical properties of a typical experimental mirror of this design. The dashed line represents the reflectance of a first surface aluminum mirror. The average (visible) reflectance of the cold mirror is higher than aluminum, while the average infrared (beyond 1 micron) transmission exceeds 80 percent.

ISOMET OPTICAL COATING NO. ICM - 15.3E

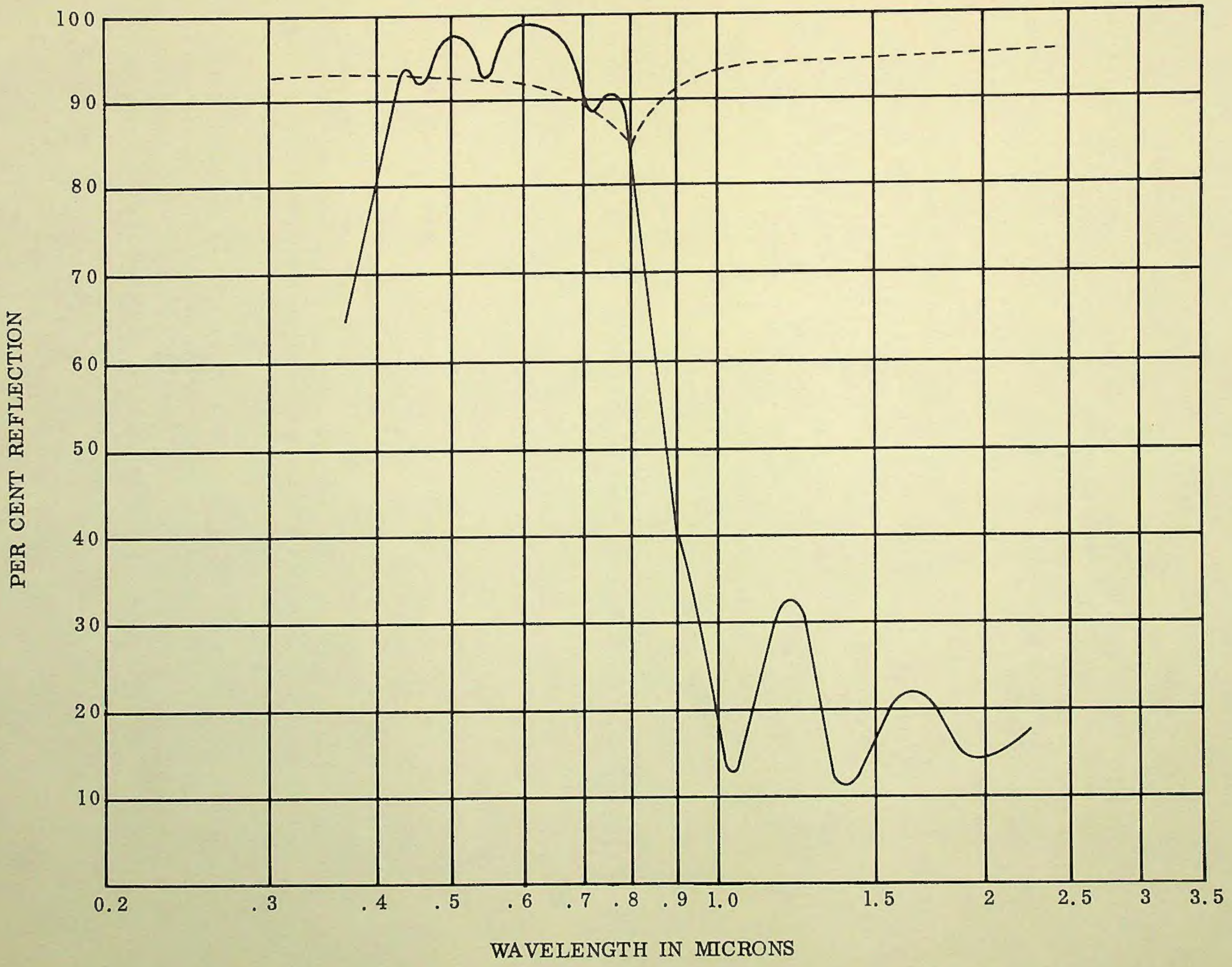


FIGURE 3

Isomet's cold mirror design, lCM-15, represents an improvement over the design discussed above. As Figure 4 indicates, the lCM-15 design has lower "holes" (transmission regions), resulting in a higher average (visible) reflectance.

The general spectral properties of the lCM-15 design can be shifted to other spectral regions on a custom basis.

PRICE AND DELIVERY

Custom Deposition	$65.00	-	3 weeks

SPHERICAL (TO QUARTERWAVE) COLD MIRRORS

4.25" diam., 45" focal length	$72.50	-	1 week
3" diam., 30" focal length	60.00	-	1 week
3" diam., 18" focal length	60.00	-	1 week

FLAT COLD MIRRORS

50 mm x 50 mm x 1 mm (plate finish)	$40.00	-	1 week
1" diam. x .375" (one surface flat to 1/20 wave)	$75.00	-	2 weeks

ISOMET OPTICAL COATING NO. ICM - 15

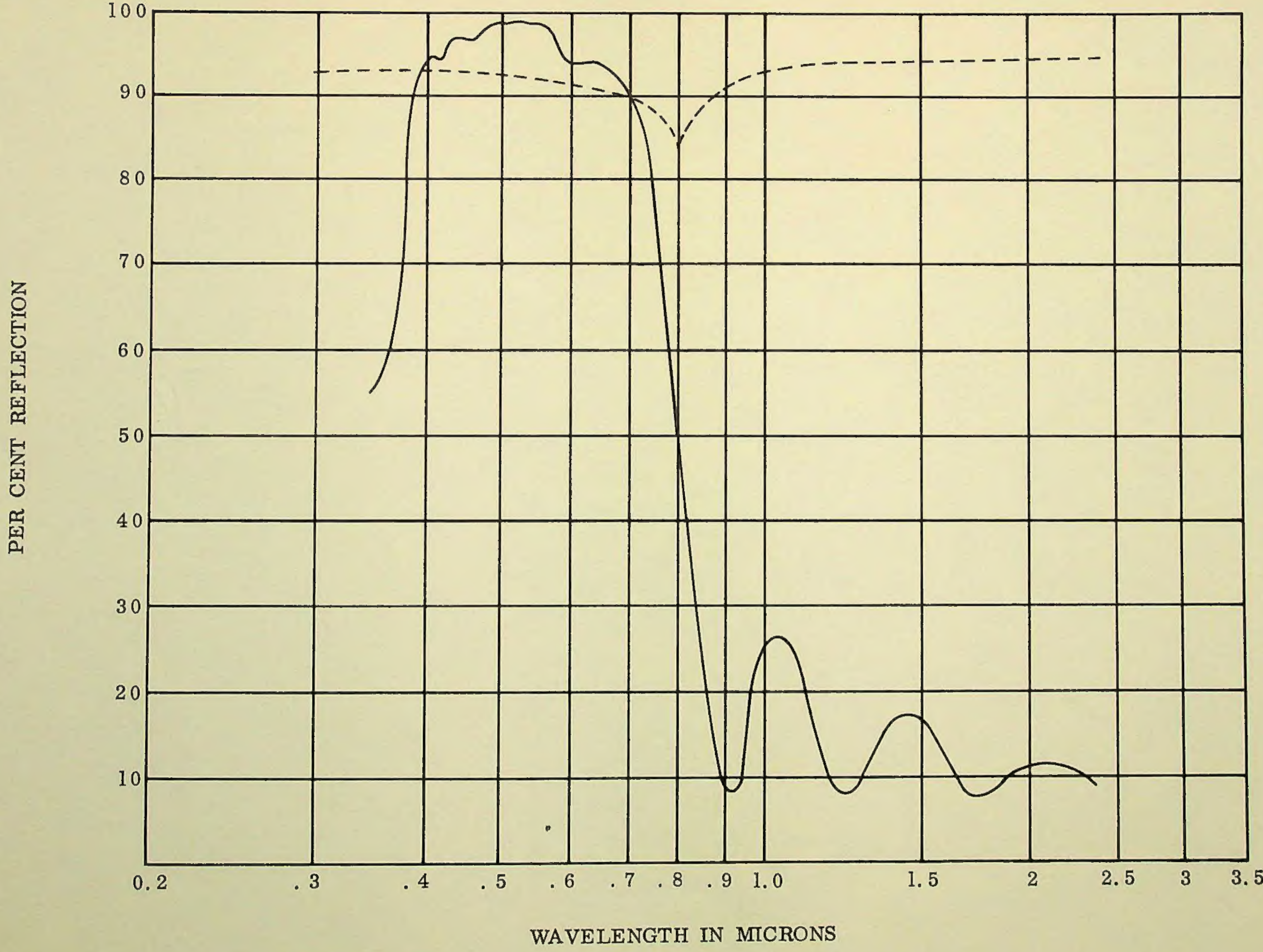


FIGURE 4

ISOMET

UTILITY TESTING MOUNT EOM-501

Isomet's Electro-Optic Light Modulator mount, EOM-501, is an adaptation of a design developed, by Isomet, for its own quality control program for testing EOLM'S. The mount is simplicity itself, offering the ultimate in economy and ease of operation.

The Utility Testing Mount provides three necessary functions for work in electro-optics. First, the mount provides an easy means for positioning an electro-optic light modulator on an optical bench. Standard Isomet EOLM'S plug directly into the mount to which voltage may be applied through a standard type HN connector. An accessory cover plate supplied with the mount allows the use of other types of EOLM'S. Secondly, the mount, which may be rotated through a full 360° allows easy alignment of the fast axis of the modulator with respect to the vibration direction of incident polarized light. Finally, three spring-loaded screws allow tilting the modulator, up to 1.5° in any direction to permit accurate alignment of the optic axis of the modulator with the optical axis of the experimental system.

The ease of alignment permitted by this mount allows an electro-optic light modulator to be made operational within minutes. Although the mount was designed primarily for economy, adjustments can be made with enough accuracy for all but the most sophisticated experiments.

PRICE: $120.00